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AUTHOR(S) A. Harvey, AT-3

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TAILORED VACUUM CHAMBERS FOR AC MAGNETS*

A. Harvey, AT-3, MS H808
Los Alamos National Laboratory, Los Alamos, NM 87545 USA

Summary

The proposed LAMPF-II accelerator has a 60-Hz booster synchrotron and a 3-Hz main ring. To provide a vacuum enclosure inside the magnets with low eddy-current losses and minimal field distortion, yet capable of carrying rf image currents and providing beam stabilization, we propose an innovative combination pipe. Structurally, the enclosure is high-purity alumina ceramic, which is strong, radiation resistant, and has good vacuum properties. Applied to the chamber are thin, spaced, silver conductors using adapted thick-film technology. The conductor design can be tailored to the stabilization requirements, for example, longitudinal conductors for image currents, circumferential for transverse stabilization. The inside of the chamber has a thin, resistive coating to avoid charge build-up. The overall 60-Hz power loss is less than 100 W/m.

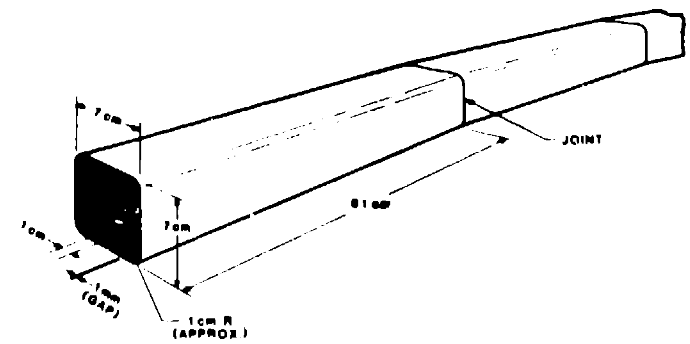

Fig. 1. Inside striped ceramic vacuum chamber.

Introduction

A major concern in designing rapid-cycling accelerators is to provide a vacuum enclosure that has tolerable heating losses and magnetic field perturbations. At the same time, it must have rf conductivity for image currents. The Fermilab booster has no vacuum enclosure in the magnet gap, but in the drive to higher intensities as well as higher magnet frequencies, rf conductors around the beam have been recognized as contributing to beam stabilization. The latest implementation of this approach at Rutherford's 50-Hz accelerator uses a metal frame inside a ceramic vacuum pipe.[1,2] The same principle of reducing the conductor width normal to the magnetic field, and so the eddy currents, is used here. For LAMPF-II (where the booster is a 60-Hz synchrotron), we have proposed a chamber for smaller gap magnets where a variety of conductor patterns can be applied to ceramic vacuum pipes to give the desired rf properties,[3] using methods and materials from thick-film technology. Adaptations of this construction can be used to provide vacuum liners for kicker magnets,[4] or to construct coils for measuring the magnetic field.

Construction

The basic mechanical structure is a high quality ceramic. Alumina of 94-99% purity is a strong radiation-resistant insulator, with good vacuum properties. Depending on the application, other combinations of properties might be desired, but for application to particle accelerator beam pipes within magnets, alumina is a good candidate material. Present manufacturing technology can produce pipes over 1 m long by isostatic pressing, with dimensional tolerances of around 2%. Better tolerances can be achieved by grinding the fired body, but in this application, that expensive step is not necessary.

Such ceramic pipes can be made in lengths up to 1.22 m long,† but because LAMPF II magnets are curved, parts of about half that length will be joined to follow the beam trajectory (see Fig. 1). Sealing glasses with a wide range of melting points can be used to make nonconducting joints.

The conductors, and dielectric layers if required, are applied using inks developed for hybrid thick-film circuits. In that technology, silk-screening is the standard method for applying the inks, but the three-dimensional nature of these components makes spray or brush application more feasible. Firing at temperatures up to 950°C in air is required to bond the individual layers together. Because of limitations on rates of temperature rise and fall (based on the mass of the substrate), inks must be selected that will withstand an extended period at high temperature. In general, such inks will not contain palladium. This elimination leaves many candidates available -pure silver is desirable to keep the resistive component of the impedance low.

If the pipe structure is a vacuum enclosure, there must be some method for attachment to the external vacuum system. Many magnets impose the restriction that the vacuum chamber be inserted in the bore from one end; therefore, there is a limitation on the size of one end connector. In addition, the rigidity of ceramic structures mandates that some flexibility be built in to the end connector. These requirements have led to the proposal for a single convolution metal extension of the chamber, brazed to the end of the ceramic.

Materials

The currently preferred candidate materials for conductor and dielectric layers of the ceramic pipe are listed below (see Fig. 2):

Step	Operation	Material	Firing Conditions
1	1st conductive layer	Englehard A 3059 (silver)	930°C in air
2	2 dielectric layers	Englehard A 2835 (glass)	850°C in air
3	2nd conductive layer	Englehard A 3059 (silver)	830°C in air
4	Protective dielectric	Englehard A 2835 (glass)	800°C in air
5	Inner Ni coating	Chemical vapor deposition	200°C

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†GTE Wesgo, Belmont, California.

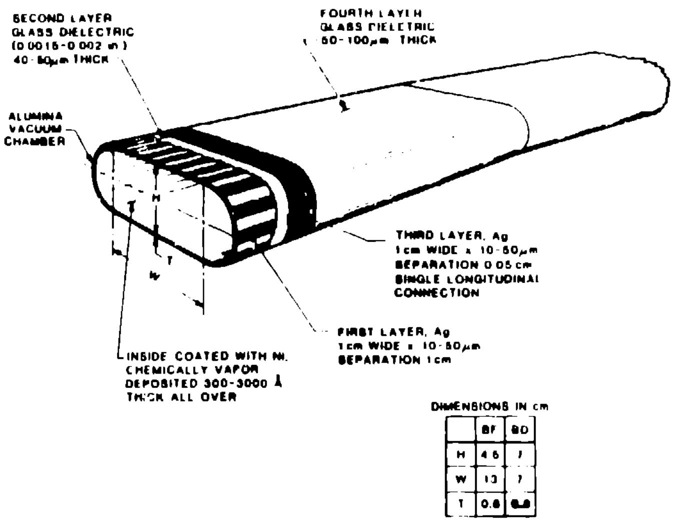


Fig. 2. Ceramic vacuum chamber with stripes and bands. BF and BD refer to the focusing and defocusing dipoles, respectively.

Step 5 provides a high-resistance coating on the interior ceramic surface to preclude charge build-up. Either pure nickel or nickel phosphide can be deposited by chemical vapor deposition (CVD). A wide variety of other resistive coatings can be sprayed on using organometallics.

Electrical Properties

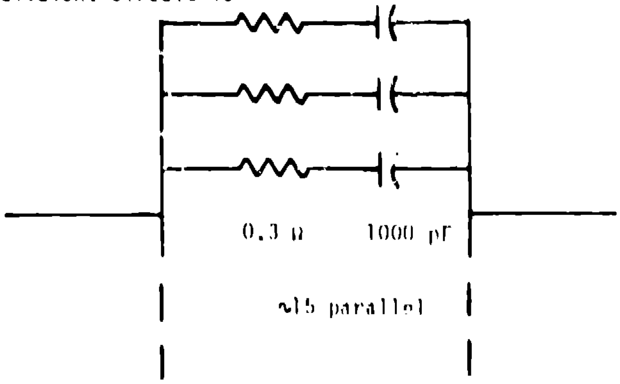
The low-frequency eddy-current power loss P in a unit length conductor of width W and thickness t, perpendicular to an alternating magnetic field of average value B_{av} and frequency f_{rep}, is

$$P = \frac{\pi^2}{12} f_{rep}(f_{up} + f_{down}) \cdot B_{av}^2 \frac{t \cdot W^3}{\rho} ,$$

where ρ is the resistivity of the conductor; f_{up} and f_{down} are the rise and fall frequencies of the magnetic field, if these are not the same.

So, using the characteristics of the LAMPF II booster,[*] with 25-μm (0.001-in.) thick conductors, the low-frequency losses with 15 parallel strips (Fig. 2) are 19.5 W/m for 60 Hz, where the magnetic field varies from 0.24 to 1.12 T, and the dc resistance per strip is 300 mΩ. The strong dependence on conductor width allows the heating loss to be reduced to any desired level.

If the coupling at one end of every strip is made by a 1000-pF capacitor (equivalent to a 2.5-cm long overlay of conductor around the circumference), the equivalent circuit is



and the 75-MHz impedance is

$$Z_{75} = \left(\frac{0.3}{15} + \frac{1}{15 \cdot j\omega \cdot 10^{-9}}\right) \text{ or } 143 \text{ m}\Omega .$$

The capacitors could be discrete components, as in the Rutherford Spallation Neutron Source (SNS), but it would be simpler to incorporate them in the chamber end. To reduce this impedance (which principally is due to the end capacitance), a dielectric with a higher dielectric constant (up to 650), or a longer overlay could be used. In addition, alternate strips could be connected to opposite ends of the chamber and coupled by the bands (Fig. 2).

The skin depth of the conductors is given by

$$\delta = \sqrt{\frac{2\rho}{\omega\mu_0}} ,$$

where ρ is the resistivity of the silver (150 mΩ per square for 25 μm thickness), μ_0 is the permeability of free space ($4\pi \times 10^{-7}$), and ω (for harmonic number n = 100 x rotational frequency) is $2\pi \times 10^8$. Therefore, δ = 4.1 μm; alternatively, the strip-line cutoff frequency for the 25 μm-thick conductor is 15.4 MHz

Radiation Resistance

Because the vacuum pipe is the material nearest the circulating particle beam, the resistance of component materials to radiation damage is of some importance. The alumina ceramic itself is quite resistant to radiation, being used at LAMPF for target cell magnet insulators and seals[*] and for beamline instruments.[*] It also withstood the heating of a localized beam spill--7 W/cm^2 in an experiment using the 800-MeV protons at Los Alamos.

The silver conductor suggested above is bonded molecularly to the alumina; that is, there is no glass frit, and we expect it to have good resistance to damage. The dielectric film is the most suspect component, but we can argue that a lossy dielectric (caused by radiation-induced conductivity) might be an advantage in suppressing higher order resonances, especially in two-layer structures as shown in Fig. 2.

Development

The construction technique described here has the potential for great versatility in the rf properties of the composite structure, and the conductor patterns shown represent our early ideas of how a desirable chamber might be fabricated. The rf impedances, longitudinal and transverse, are of great importance to the accelerator designer, and we plan to make measurements of these properties on prototype chambers (see Figs. 3 and 4).

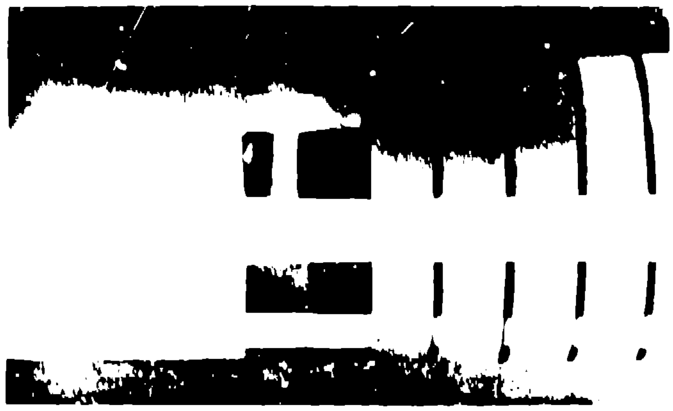


Fig. 3. Externally applied silver stripes and bands.

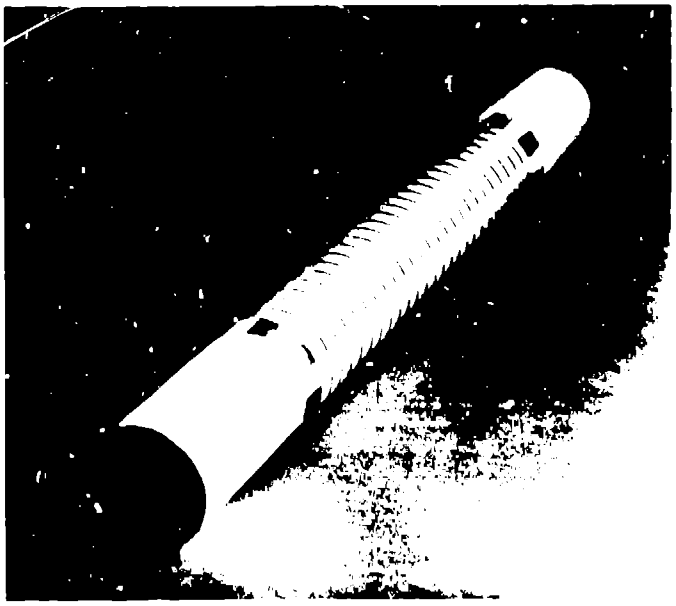


Fig. 4. In this view, the internal nickel coating also can be seen.

Most reported measurements of longitudinal impedance are comparative, that is, comparing the structure of interest to an equal length of copper or aluminum pipe.[7,8] Such substitution measurements will be made on our composite chambers, particularly to determine if external conductors (Fig. 2) are more lossy than internal conductors (Fig. 1). Clearly, external conductors are easier to apply, but the rf field has to penetrate the ceramic, which may increase the losses.[9]

It will be important to determine if the presence of a few hundred angstroms of a ferromagnetic material (Ni) in the magnet gap significantly affects the magnetic field distribution. Many other coating materials and processes are available, such as aluminizing, sputtering, or the Fermilab indium oxide process,[10] all more difficult to implement.

Acknowledgments

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References

1. J. R. J. Bennett and R. J. Elsey, "Glass Jointed Alumina Vacuum Chambers," IEEE Trans. Nucl. Sci. 28 (3) (1981), 3336.

2. Bulletin of the Rutherford Appleton Laboratory, #12, August 23, 1982.

3. "A Proposal to Extend the Intensity Frontier of Nuclear and Particle Physics to 45 GeV (LAMPF II)," Los Alamos National Laboratory document LA-UR-84-3982, December 1984.

4. S. Giordano, "A Low Coupling Impedance Double Helix Structure for Use in a Ferrite Kicker Magnet," IEEE Trans. Nucl. Sci. 30 (4) (1983), 3496.

5. A. Harvey, "Radiation-Hardened Magnets Using Mineral-Insulated Conductors," Los Alamos National Laboratory report LA-5306-MS, June 1973.

6. E. W. Hoffman, R. J. Macek, O. van Dyck, D. Lee, A. Harvey, and J. Caine, "High-Intensity-Beam Profile Monitors for the LAMPF Primary Beam Lines," IEEE Trans. Nucl. Sci. 26 (3) (1979), 3420.

7. J. Peters, "Bench Measurements of the Energy Loss of a Stored Beam to Vacuum Components," IEEE Trans. Nucl. Sci. 24 (3) (1977), 1446.

8. P. B. Wilson, J. B. Styles, and K. L. Bane, "Comparison of Measured and Computed Loss to Parasitic Modes in Cylindrical Cavities with Beam Ports," Stanford Linear Accelerator Center report SLAC-PUB-1908, March 1977.

9. A. Piwinski, "Penetration of the Field of a Bunched Beam Through a Ceramic Vacuum Chamber with Metallic Coating," IEEE Trans. Nucl. Sci. 24 (3) (1977), 1364.

10. E. B. Tilles, G. H. Biallas, M. A. Harrison, P. A. Adderley, and M. P. May, "Long Ceramic Beam Tubes for Accelerator Magnets," IEEE Trans. Nucl. Sci. 30 (4) (1983), 2847.